

Electron Spectroscopy

Description:

The Electron Spectroscopy Program has undergone a major shift in emphasis in recent years. The development of a range of new instrumentation is allowing a concerted effort in the general area of correlated systems, including the cuprates, the basis of the high T_c superconductors, the related nickelates, and the manganates, the basis of the colossal magneto-resistance materials. Aside from the obvious technological potential, these materials offer a whole range of new challenges in fundamental physics. Work also continues on a more limited basis in the general area of the electronic and magnetic structure of surfaces and thin films.

New experimental capabilities include a high resolution photoemission system having the ability to measure photoemission spectra for a large range of angles simultaneously. New capabilities have also been developed in infra-red spectroscopy. A commercially available Bruker spectrometer has been coupled to a beam line at the National Synchrotron Light Source and a second spectrometer installed within the Physics Department. A new Pulsed laser Deposition facility, recently established in the Physics Dept. is now producing thin films of various oxides. Some of this effort will be integrated into the BNL Nanocenter initiative.

Recent Program Highlights

Demonstrated the non-Fermi liquid like nature of the single particle excitations in the optimally doped high T_c superconductor. Science 285, 2110-2113 (1999).

Measured the optical response of a perovskite oxide with the highest known dielectric-constant. Science 293, 673-676 (2001)

Demonstrated the role of the magnetic resonance mode in the single particle excitation spectrum of the cuprate $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$. Phys. Rev. Lett. 87(17), 177007 (2001).

Determined the electron phonon coupling constant from transport and optical studies of c-axis oriented superconducting MgB_2 films. Phys. Rev. Lett. (in print) and Cond-mat/0107349.

Correlated the observation of well defined coherent excitations with a dimensional crossover in layered strongly correlated metals", Submitted to Nature.

Impact:

In the past three years, the group has established itself as one of the leading Spectroscopy groups in the world working in the area of strongly correlated electrons. This is evidenced by the number of invited talks and by the high citation rate for recent publications from the group.

Interactions:

Current Collaborations: Boston University, University of Connecticut, LaJolla UCSD, Temple University, Institute of Physics (Zagreb), Pohang University (Korea), Princeton, NRL, and SUNY-Stony Brook.

Personnel:

Peter D. Johnson (Group Leader), Chris Homes, Weidong Si (Research Associate), Myron Strongin, Jiufeng Tu (Research Associate), and Tonica Valla.

Recognition:

In the past three years, 28 invited talks and Department Colloquia, and one Plenary talk. Two Fellows of the APS. In 2001 Peter Johnson was awarded the Brookhaven Lab Science and Technology award.

Budget: \$1340K

Condensed Matter Physics—Electron Spectroscopy

Current Staff

Peter D. Johnson	Photoemission, correlated systems including superconductivity and magnetism, quantum wells.
Myron Strongin	Infra-red spectroscopy, disorder in thin films, superconductivity.
Christopher Homes	Infra-red spectroscopy, superconductivity, correlated systems.
Tonica Valla	Photoemission, superconductivity, quantum wells.
Jiufeng Tu (Research Associate)	Infra-red spectroscopy, superconductivity, disorder in thin films.
Weidong Si (Research Associate)	Pulsed Laser Deposition
Fran Loeb (Technical Staff)	
Arlene Rementer (1/2) Secretary	

Funding from other sources:-

LDRD: “Self-organized Nanoparticles for probing Charge Transfer” \$50K

Research Facilities

High Resolution Scienta Photoelectron Spectrometer
Inverse Photoemission Spectrometer

High Brightness Wide Spectra Range IR Spectrometer
Lab based 133 Bruker IR Spectrometer

Pulsed Laser Deposition Facility

Future Plans

Development of Laser Driven MBE
Development of new capabilities in Ultra High Energy Resolution Photoemission
With its' many electron-spectroscopy-based probes, the group will be heavily involved in the Nanocenter initiative now being developed at BNL.

Condensed Matter Physics—Electron Spectroscopy

Collaborators and Institutions outside of BNL

P. Allen	Physics Dept., SUNY Stony Brook, New York
D.N. Basov	University of California at San Diego, La Jolla, California
D.A. Bonn and W.N. Hardy	University of British Columbia, Vancouver, B.C. Canada
D. Buttrey	University of Delaware
R. Cava	Chemistry Dept. Princeton University
A.V. Fedorov	Dept. of Physics Colorado University, Boulder Colorado
P. Fournier and R.L. Greene	University of Maryland
J.P. Franck	University of Alberta, Edmonton, Alberta, Canada
L. Greene	Physics Dept, University of Illinois, Urbana, Illinois
D.G. Hinks	MSD, Argonne National Laboratory
C. Kendziora	Naval Research Laboratory
N. Koshizuka	ISTEC Tokyo, Japan
F. Liu	Institute of High Energy Physics, Beijing
L. Mihaly	SUNY Stony Brook, Stony Brook, New York
M. Milun and P. Pervan	Institute of Physics, Zagreb
A.P. Ramirez	Los Alamos National Laboratory
K.E. Smith	University of Boston, Boston, Massachusetts
D.R. Strongin	Temple University, Philadelphia, Pennsylvania
S. Tajima	ISTEC, Shinonome 1-10-13, Tokyo 135, Japan
T. Timusk	McMaster University, Hamilton, Ontario, Canada
S. Uchida	University of Tokyo, Yayoi 2-11-16, Bunkyo-ku, Tokyo, Japan
B. Wells and Z. Yusof	Physics Dept., U. Connecticut, Storrs, Connecticut
D.P. Woodruff	Physics Dept., University of Warwick, UK

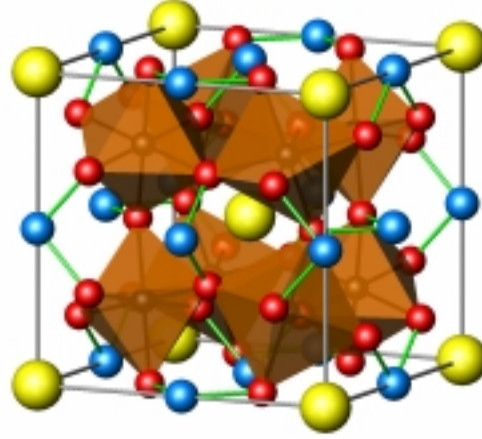
Internal BNL Collaborations

L. Carr	NSLS, BNL, IR studies of MgB_2
G. Gu	Physics Dept., BNL, PES Studies of High T_c Superconductivity
Q. Li	Materials Science Dept., BNL, PES Studies of High T_c Superconductivity
A. Moodenbaugh	Materials Science dept., BNL, PES Studies of High T_c Superconductivity
S. Shapiro	Physics Dept., BNL, IR Studies of High Dielectric materials
T. Vogt	Physics Dept., BNL, IR Studies of High Dielectric materials, Soft X-ray emission studies of MgB_2

Recent Research Highlights

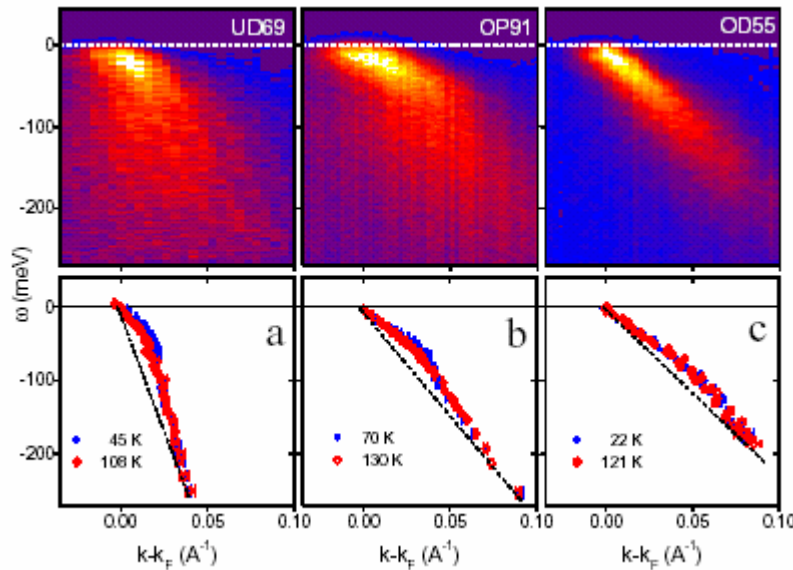
Optical properties of the giant dielectric constant material $\text{CaCu}_3\text{Ti}_4\text{O}_{12}$.

Transport measurements of the cubic perovskite-related material calcium copper titanium oxide show that it has one of the highest known values at room temperature for the static dielectric constant, $\epsilon_0 \sim 10^5$. However, it drops by a factor of 1000 below 100 K without any change in the long-range crystallographic structure. Optical measurements provide another method of measuring the real and imaginary parts of the dielectric constant, and have provided the first clues to the high value for ϵ_0 , and mechanism behind the sudden decrease of ϵ_0 at low temperature [Science **293**, 673 (2001)].



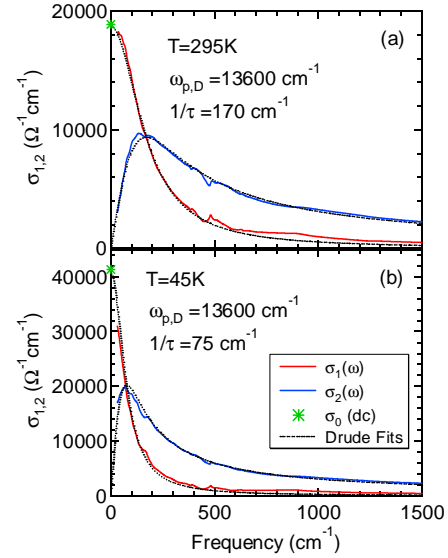
On the Doping and Temperature Dependence of the Mass Enhancement Observed in the Cuprate $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$

High-resolution photoemission is used to study the electronic structure of the cuprate superconductor, $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$, as a function of hole doping and temperature. A kink observed in the band dispersion in the nodal or (π, π) direction has previously been associated with scattering from phonons. However, our studies indicate that certainly in the superconducting state the kink is associated with coupling to a resonant mode observed in neutron scattering. From the measured real part of the self energy it is possible to extract a coupling constant which is largest in the underdoped regime, then decreases continuously into the overdoped regime. [Phys. Rev. Lett. **87**, 177007 (2001)]



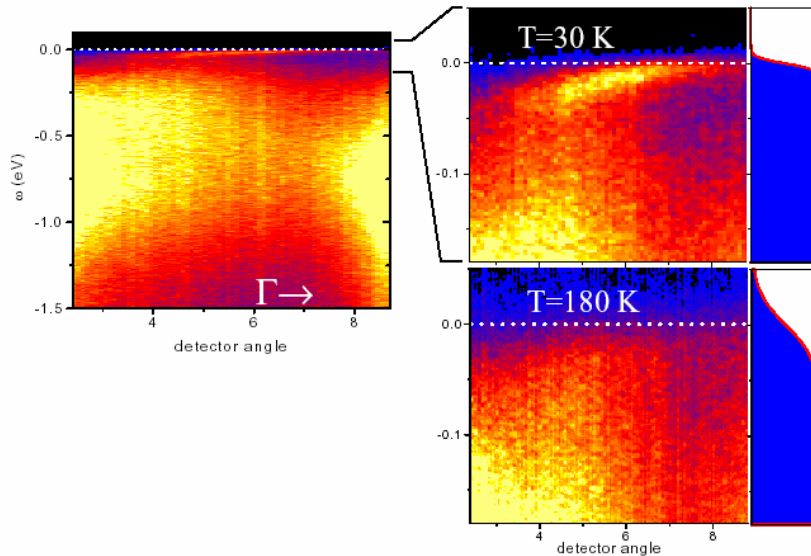
Optical studies of charge dynamics in c-axis oriented superconducting MgB₂ films

The recent discovery of superconductivity in the simple binary compound MgB₂ with T_c of 39 K has generated considerable scientific interest. We have measured the optical conductivity and DC resistivity of c-axis oriented PLD grown superconducting ($T_c = 39.6$ K) MgB₂ films (~450 nm). Using both optical and transport data, we find $\lambda_{tr,ab} = 0.13 \pm 0.02$. The small measured $\lambda_{tr,ab}$ value poses a serious problem for the strong electron-phonon coupling picture. Indeed an unconventional electron-phonon mechanism would be required to understand the high transition temperature. [Cond-mat/0107349 and Phys. Rev. Lett. (in print)]



Coherence-Incoherence and Dimensional Crossover in Layered Strongly Correlated Metals

Many modern “quasi-low-dimensional” materials consist of 1D or 2D building blocks, relatively loosely connected into a 3D whole. Their physical properties are therefore highly anisotropic. They may conduct electrical (or thermal) currents in one direction much better than in another. Within the classical Fermi-liquid picture currents are carried by “quasiparticles” (QP) and the resistivity is proportional to the QP scattering rate. The anisotropy is then a consequence of different hopping integrals for different directions. Problems with this picture appear when conductivities become uncoupled or disproportionate. In particular, different temperature behavior in different directions suggests that the currents are carried by collective excitations instead of QPs. We have studied the single-particle excitations in systems that display a crossover in the least conductive direction (c-axis), from insulating-like, at high temperatures, to metallic-like character at low temperatures, while being metallic over the whole temperature range in the other two directions. Sharp QP-like excitations exist in the photoemission spectra in the 3-D low-temperature regime ($T < T_M$), but not in the 2-D-like high-temperature phase ($T > T_M$). This points to a strong correlation between the effective dimensionality of a system and the character of its excitations. [Submitted to Nature]



Recent Publications
FY 1999

Basov, D.N., Woods, S.I., Katz, A.S., Singley, E.J., Dynes, R.C., Xu, M., Hinks, D., Homes, C.C., and Strongin, M. Sum rules and interlayer conductivity of high- T_c cuprates. *Science* **283**, 49 (1999).

Crandles, D.A., Nicholas, B., Dreher, C., Homes, C.C., McConnell, A.W., Clayman, B.P., Gong, W.H., and Greedan, J.E. Optical properties of highly-reduced SrTiO_{3-x} . *Phys. Rev. B* **59**, 12842-12846 (1999).

Fedorov, A.V., Valla, T., Johnson, P.D., Li, Q., Gu, G.D., and Koshizuka, N. Temperature dependent photoemission studies of optimally doped $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$. *Phys. Rev. Lett.* **82**, 2179 (1999).

Franck, J.P., Isaac, I., Chen, W., Chrzanowski, J., Irwin, J.C., and Homes, C.C. Isotope studies of the CMR compounds $\text{La}_{1-x}\text{Ca}_x\text{MnO}_{3+\delta}$. *J. Superconductivity* **12**(1), 263-267 (1999).

Golovanov, V., Mihaly, L., Homes, C., McCarroll, W., Ramanujachary, K., and Greenblatt, M. Temperature and magnetic field dependent optical spectral weight in the cation-deficient colossal magnetoresistance material $\text{La}_{0.936}\text{Mn}_{0.982}\text{O}_3$. *Phys. Rev. B* **59**(1), 153-156 (1999).

Henning, P.F., Homes, C.C., Maslov, S., Carr, G.L., Basov, D.N., Nikolic, B., and Strongin, M. Infrared studies of the onset of conductivity in ultra-thin Pb films. *Phys. Rev. Lett.* **83**(23), 4880-4883 (1999).

Homes, C.C., Bonn, D., Liang, R., Hardy, W., Basov, D., Timusk, T., and Clayman, B. Effect of Ni impurities on the optical properties of $\text{YBa}_2\text{Cu}_3\text{O}_{6+y}$. *Phys. Rev. B* **60**(13), 9782-9792 (1999).

Johnson, P.D. Workshop on complex materials. *Synchrotron Radiat. News* **12**(5), 5 (1999).

Johnson, P.D., Valla, T., Fedorov, A., Reisfeld, G., and Hulbert, S.L. High-resolution photoemission studies of complex materials. Proceedings of the 11th U.S. National Synchrotron Radiation Instrumentation Conference (SRI'99), AIP Conference Proceedings 521, 73 (2000).

Valla, T., Fedorov, A.V., Johnson, P.D., and Hulbert, S.L. Many-body effects in angle-resolved photoemission: quasiparticle energy and lifetime of a Mo(110) surface state. *Phys. Rev. Lett.* **83**(10), 2085-2088 (1999).

Valla, T., Johnson, P.D., Dhesi, S.S., Smith, K.E., Doppalapudi, D., Moustakas, T.D., and Shirley, E.L. Unoccupied band structure of Wurtzite GaN(0001). *Phys. Rev. B* **59**(7), 5003-5007 (1999).

Valla, T., Fedorov, A.V., Johnson, P.D., Wells, B.O., Hulbert, S.L., Li, Q., Gu, G.D., and Koshizuka, N. Evidence for quantum critical behavior in the optimally doped cuprate $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$. *Science* **285**, 2110-2113 (1999).

Xue, J., Duda, L., Smith, K., Fedorov, A., Johnson, P.D., Hulbert, S., McCarroll, W., and Greenblatt, M. Electronic structure near the Fermi surface in the quasi-one-dimensional conductor $\text{Li}_{0.9}\text{Mo}_6\text{O}_{17}$. *Phys. Rev. Lett.* **83**(6), 1235-1238 (1999).

FY 2000

Basov, D.N., Bratkovsky, A.M., Henning, P.F., Zink, B., Hellman, F., Wang, Y.J., Homes, C.C., and Strongin, M. Infrared probe of metal-insulator transition in $\text{Si}_{1-x}\text{Gd}_x$ and $\text{Si}_{1-x}\text{Y}_x$ amorphous alloys in magnetic field. *Europhys. Lett.* (accepted).

Cao, G., Crow, E., Guertin, R.P., Henning, P.F., Homes, C.C., Strongin, M., Basov, D. and Lochner, E. Charge density wave formation accompanying ferromagnetic ordering in quasi-one dimensional BaIrO₃. Sol. State Commun. 113, 657 (2000).

Elsetinow, A.R., Guevremont, J.M., Strongin, D.R., Schoonen, M.A.A., and Strongin, M. Oxidation of {111} and {100} planes of pyrite: effects of surface atomic structure and preparation method. American Mineralogist 85, 623 (2000).

Fedorov, A.V., Brazovskii, S.A., Muthukumar, V.N., Johnson, P.D., Xue, J., Duda, L.-C., Smith, K.E., McCarroll, W.H., Greenblatt, M., and Hulbert, S.L. Direct observation of temperature-dependent Fermi surface nesting vectors in a quasi-one-dimensional conductor. J. Phys.: Condensed Matter 12, L191-L198 (2000).

Homes, C.C., McConnell, A.W., Clayman, B.P., Bonn, D.A., Liang, R., Hardy, W.N., Inoue, M., Negishi, H., Fournier, P., and Greene, R.L. Phonon screening in high-temperature superconductors. Phys. Rev. Lett. 84, 5391 (2000).

Valla, T., Kralj, M., Siber, A., Milun, M., Pervan, P., Johnson, P.D., and Woodruff, D.P. Oscillatory electron-phonon coupling in ultra-thin silver films on V(100). J. Phys.: Condens. Matter 12, L477-L482 (2000).

Valla, T., Fedorov, A.V., Johnson, P.D., Li, Q., Gu, G.D., and Koshizuka, N. Temperature dependent scattering rates at the Fermi surface of optimally doped Bi₂Sr₂CaCu₂O_{8+δ}. Phys. Rev. Lett. 85(4), 828-831 (2000).

Valla, T., Fedorov, A.V., Johnson, P.D., Xue, J., Smith, K.E., and DiSalvo, F.J. Charge-density-wave induced modifications to the quasiparticle self-energy in 2H-TaSe₂. Phys. Rev. Lett. 85(22), 4759 (2000).

FY 2001

Basov, D.N., Homes, C.C., Singley, E.J., Strongin, M., Timusk, T., Blumberg, G., van der Marel, D. Unconventional energetics of the Pseudogap state and of superconducting state in high-T_c cuprates. Phys. Rev. B. 63, 134514 (2001).

Bernhard, C., Holden, T., Humlicek, J., Munzar, D., Golnik, A., Klaser, M., Wolf, Th., Carr, L., Homes, C., Keimer, B., and Cardona, M. In-plane polarized collective modes in detwined Yba₂Cu₃O_{6.95}. Phys. Rev. Lett. (submitted).

Dordevic, S.V., Singley, E.J., Basov, D.N., Komiya, S., Sun, X.F., Abe, Y., Ando, Y., Bucher, E., Homes, C.C., and Strongin, M. Interplane transport and superfluid density in layered superconductors. Phys. Rev. B. (submitted).

Fedorov, A.V., Valla, T., Liu, F., Johnson, P.D., Weinert, M., and Allen, P.B. A spin resolved photoemission study of photohole lifetimes in ferromagnetic gadolinium. Phys. Rev. Lett. (submitted) and Cond-mat/0106453.

Griffiths, P.R. and Homes, C.C. Instrumentation for far-infrared spectroscopy. In: Handbook of Vibrational Spectroscopy, Vol. 1 (Theory and Instrumentation), John Chalmers and Peter Griffiths, Editors, Wiley & Sons, New York, Publisher.

Homes, C.C., Vogt, T., Shapiro, S.M., Wakimoto, S., and Ramirez, A.P. Optical response of high-dielectric-constant perovskite-related oxide. Science 293, 673-676 (2001)

Jackson, R.S., Michaelian, K.H., and Homes, C.C. Photoacoustic spectroscopy using a synchrotron light source. Proceedings of the Optical Society of America (OSA), in: *Fourier Transform Spectroscopy*, OSA Technical Digest, pp. 161-163, Washington, D.C., 2001. (ISBN:1-55752-664-8).

- Johnson, P.D., Valla, T., Fedorov, A., Yusof, Z., Wells, B.O., Li, Q., Moodenbaugh, A.R., Gu, G.D., Koshizuka, N., Kendziora, C., Jian, S., and Hinks, D.G. On the doping and temperature dependence of the mass enhancement observed in the cuprate $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$. *Phys. Rev. Lett.* **87**(17), 177007 (2001).
- Johnson, P.D., Fedorov, A.V., and Valla, T. Photoemission studies of self-energy effects in cuprate superconductors. *J. Electron Spectroscopy & Related Phenomena* **117-118**, 153-164 (2001).
- Kralj, M., Siber, A., Pervan, P., Milun, M., Valla, T., Johnson, P.D., and Woodruff, D.P. Temperature dependence of photoemission from quantum-well states in $\text{Ag}/\text{V}(100)$: moving surface-vacuum barrier effects. *Phys. Rev. B* **64**, 085411 (2001).
- McGuinness, C., Smith, K.E., Butorin, S.M., Guo, J.H., Nordgren, J., Vogt, T., Schneider, G., Reilly, J., Tu, J.J., Johnson, P.D., and Shuh, D.K. High resolution x-ray emission and adsorption study of the valence band electronic structure of MgB_2 . *Europhysics Letters*, **56**, 112 (2001).
- Michaelian, K.H., Jackson, R.S., and Homes, C.C. Synchrotron infrared photoacoustic spectroscopy. *Rev. Sci. Instrum.* (submitted).
- Pigos, J.M., Jones, B.R., Zhu, Z.-T., Musfeldt, J.L., Homes, C.C., Koo, H.-J., Whangbo, M.-H., Schlueter, J.A., Ward, B.H., Wang, H.H., Geiser, U., Mohtasham, J., Winter, R.W., and Gard, G.L. Infrared and optical properties $\beta'-(\text{ET})_2\text{SF}_5\text{CF}_2\text{SO}_3$: evidence for a 45 K spin-Peierls transition. *Chem. Mater.* **13**, 1326-1333 (2001).
- Smith, K.E., Xue, J., Duda, L., Fedorov, A., Johnson, P.D., Hulbert, S.L., McCarroll, W., and Greenblatt, M. Recent high resolution photoemission studies of electronic structure in quasi-one dimensional conductors. *J. Electron Spectroscopy & Related Phenomenon* **117-118**, 517-526 (2001).
- Tu, J.J., Homes, C.C., Gu, G.D., Basov, D.N., Loureiro, S.M., Cava, R.J., and Strongin, M. Optical studies of charge dynamics in the optimally-doped $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ and the non-superconducting $(\text{Bi}_{0.5}\text{Pb}_{0.5})_2\text{Ba}_3\text{Co}_2\text{O}_8$ single crystals. *Phys. Rev. Lett.* (submitted) and *Cond-mat/0104208*.
- Tu, J.J., Carr, G.L., Perebeinos, V., Homes, C.C., Strongin, M., Allen, P.B., Kang, W.N., Choi, E.-M., Kim, H.-J., and Lee, S.-I. Optical studies of charge dynamics in c-axis oriented superconducting MgB_2 films. *Phys. Rev. Lett.* (accepted) and *Cond-mat/0107349*.
- Tu, J.J., Homes, C.C., Gu, G.D., and Strongin, M. A systematic optical study of phonon properties in optimally doped $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$. *Physica B* (accepted).
- Wells, B.O., Yusof, Z., Valla, T., Fedorov, A.V., Johnson, P.D., Dendziora, C., Jian, S., and Hinks, D. ARPES evidence for a quasiparticle liquid in overdoped $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$. Proceedings of the International Conference on Vacuum Ultraviolet Radiation Physics (VUVXIII), Trieste, Italy, July 23-27, 2001.
- Yusof, Z., Wells, B.O., Valla, T., Fedorov, A.V., Johnson, P.D., Li, Q., Kendziora, C., Jian, S., and Hinks, D.G. Quasiparticle liquid in the highly overdoped $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$. *Phys. Rev. Lett.* (submitted) and *Cond-mat/0104367*.
- G. Tzamalís, N.A. Zaidi, C.C. Homes, and A.P. Monkman, Infrared optical properties of polyaniline doped with 2-acrylamido-2-methyl-1-propanesulphonic acid (AMPSA), *J. Phys.: Condens. Matter* **13**, 6297 (2001)